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(54) Title: DOWNHOLE DEPOSITION MONITORING SYSTEM
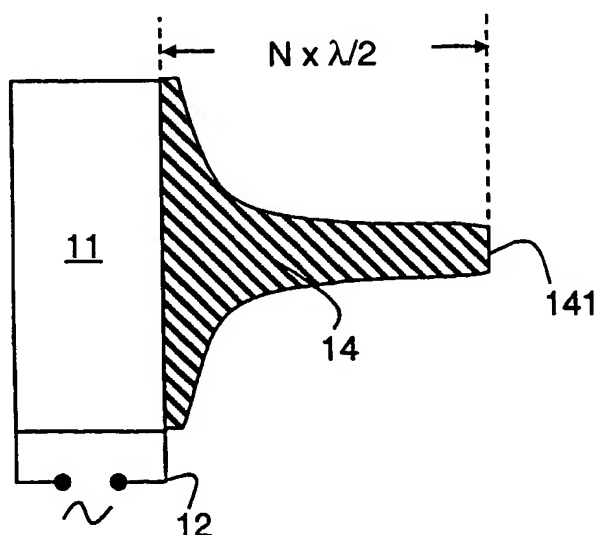
(57) Abstract: Described is a downhole apparatus for detecting and removing deposits from a surface exposed to wellbore fluids. The apparatus can monitor the rate of deposition and subsequently remove the deposited material. The combination of detection apparatus and removal apparatus provides a downhole instrument with self-cleaning operation mode.

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Downhole Deposition Monitoring System

This invention relates to apparatus and methods for monitoring
solid deposits of material in a wellbore and operating downhole
5   sensors and other wellbore equipment. Particularly, the
invention relates to such apparatus and methods for sensing and
removing solid deposits in hydrocarbon wells.

10   BACKGROUND OF THE INVENTION

The formation of both organic and inorganic deposits in the near
wellbore region of producing formations and on the tubing of a
producing hydrocarbon well can be a major and costly problem.
15   See, e.g. Allen, T.O. and Roberts, A.P., *Production Operations*,
Vol. 2, 2nd edition, pp. 11-19 and 171-181, OGCI, Tulsa, Ok.
(1982); Cowan, J.C and Weintritt, D.J., *Water-formed Scale
Deposits*, Gulf Publishing Co., Houston (1976). The deposits can
seriously impede the productivity of wells by reducing the near
20   wellbore permeability of producing formations and progressively
restrict the diameter of the tubing.

The formation of inorganic deposits, or scale, is caused by the
precipitation of inorganic salts from produced water. Calcium
25   carbonate scale is usually formed by the change in the pressure
and temperature of the produced water in the near wellbore and
in the production tubing. Barium, strontium and calcium sulphate
scales are usually formed by the mixing of formation water and
seawater injected into producing wells; the high concentration
30   of sulphate in seawater mixes with the high concentrations of
divalent cations in formation waters with the resulting
precipitation of the sulphate salts. The formation of scale may
be partly prevented by water shut-off treatments and the use of
scale inhibitors. Once formed, scale can be removed only with
35   some difficulty; calcium carbonate scale can be dissolved by

mineral acids and barite scale can be removed by milling or
scale dissolvers such as EDTA. See, e.g. Putnis, A, Putnis, C.V.
and Paul, J.M., "The efficiency of a DTPA-based solvent in the
dissolution of barium sulfate scale deposits", *SPE International*

5   *Symp. Oilfield Chemistry*, San Antonio, Texas, February 1995, SPE
29094. In extreme cases the production tubing must be removed
and replaced, although the presence of radioactive scale (due to
the presence of radium salts) can make scale disposal an
environmental issue.

10

The production of hydrocarbons frequently causes the
precipitation of organic precipitates such as paraffin waxes and
asphaltenes. These organic precipitates are caused by changes in
the pressure and temperature of the produced fluids in the near

15 wellbore. The precipitates can be removed with solvent washes,
although the disposal of the solvent after cleaning represents
an increasing environmental problem.

The solubility of various inorganic and organic species can be

20 predicted from thermodynamic models of the electrolyte solutions
or hydrocarbons. See, e.g. Jasinski, R, Taylor, K. and
Fletcher, P., "Calcite scaling – North Sea HTHP wells", *SPE
Symp. Oilfield Scale*, Aberdeen, January 1999; Calange, S.,
Ruffier-Meray, V. and Behar, E., "Onset crystallization

25 temperature and deposit amount for waxy crudes: experimental
determination and thermodynamic modelling", *SPE International
Symp. Oilfield Chemistry*, Houston, Texas, February 1997, SPE
37239. However, thermodynamic models are essentially
equilibrium models and they cannot predict any details of the

30 precipitation process such as the location of precipitation, the
rate of precipitation or the degree of supersaturation that the
fluid can tolerate.

Several patents and papers have described both acoustic and non-

35 acoustic methods for sensing the formation of scale in producing

hydrocarbon wells and similar environments. An acoustic method
for measuring the thickness of metal oxide corrosion products on
the inside of boiler tubes has been described. See Lester,
S.R., "High frequency ultrasonic technique for measuring oxide

5   scale on the inner surface of boiler tubes", *US Patent*
4,669,310, June 2, 1987. The thickness of oxide scale is
determined by the time of flight of an acoustic pulse applied
from the external surface of the pipe. The frequency of the
acoustic pulse was 50 MHz, which enabled a scale thickness of

10   approximately 0.1 mm to be detected. The use of an automated
ultrasonic inspection system for determining the thickness of
scale formation which has formed on the inside of heat transfer
tubes in boilers has been described. See Okabe, Y., Iwamoto,
K., Torichigai, M., Kaneko, S., Ichinari, J. and Koizumi, K.,

15   "Automated ultrasonic examination system for heat transfer tubes
in a boiler", *US Patent* 4,872,347, October 10, 1989. A rotating
transducer was inserted into the tubes and their diameter as a
function of location determined by the reflection of sound from
the scale-water interface. An acoustic wireline logging tool,

20   Schlumberger's Cement Evaluation Tool (CET), has been used to
determine the accumulation of scale on the casing of geothermal
wells. See, US Patent No 5,072,388, to O'Sullivan et al. The
interfaces between the scale and wellbore fluid and the scale
and the casing are determined by the transit time of the

25   acoustic waves, which have a frequency of approximately 0.5 MHz.
US Patent 5,092,176 disclosed a method for determining the
thickness of scale on the inside of a water pipe by the
attenuation of acoustic energy emitted and received by a
transducer on the outside of the pipe. The optimum frequency

30   range for the ultrasound was observed to be 3-7 MHz. For
example, measurements made using ultrasound below a frequency of
3 MHz gave poor sensitivity to scale thickness and beam
spreading was observed to be a problem. An acoustic method of
identifying scale types and scale thickness in oil pipelines

35   using the attenuation in the reflected acoustic signal from a

tool that is moved through the inside of the pipe has been described. See, Gunarathne, G.P.P. and Keatch, R.W., "Novel techniques for monitoring and enhancing dissolution of mineral deposits in petroleum pipelines", *SPE Offshore Europe*

5   *Conference*, Aberdeen, Sept. 1995, SPE 30418 (hereinafter "Gunarathne"); Gunarathne, G.P.P. and Keatch, R.W., "Novel techniques for monitoring and enhancing dissolution of mineral deposits in petroleum pipelines", *Ultrasonics*, **34**, 411-419 (1996) (hereinafter "Gunarathne and Keatch"). The frequency of

10   the ultrasound used was in the range 3.5-5.0 MHz, which allowed the thickness of barium sulphate scale on steel to be measured to an accuracy of ±0.5 mm.

     US Patent 5,661,233 (hereinafter "Spates et al.") disclosed

15   several acoustic-wave devices for determining the deposition of organic precipitates, such as paraffin wax, on to a sensing surface immersed in a petroleum-based fluid. The acoustic measurements were made with devices using various acoustic modes: surface acoustic waves and thickness shear, acoustic

20   plate and flexural plate modes. The devices measured changes in the damping voltage and resonant frequency of the device as the wax precipitate formed, although no details were disclosed regarding the operating frequencies of the acoustic devices or the acoustic power they generated. Spates *et al.* discussed

25   periodic cleaning of the sensing surface of the acoustic device by heating the surface to melt the paraffin wax. However, the use of acoustic energy to clean the organic precipitates from the acoustic sensor was not disclosed or suggested. Several applications of the measurement of wax accumulation were

30   described, including location of acoustic devices on the sea floor to monitor the production of hydrocarbon from oil wells and guide well treatments. The application of a quartz microbalance to measure simultaneously mass loading and liquid properties has been described. See, *US Patent* 5,201,215;

35   Martin, S.J., Granstaff, V.E. and Frye, G.C., "Characterisation

of a quartz crystal microbalance with simultaneous mass and
liquid loading", *Anal. Chem.*, **63**, 2272-2281 (1991) (collectively
hereinafter "Granstaff and Martin"). The authors used changes
in the resonant frequency and magnitude of the maximum
5 admittance of a quartz microbalance to differentiate between
changes in the mass of material deposited from a liquid and
changes in the properties of the liquid (density and viscosity).
The operating frequency of the quartz microbalance was close to
5 MHz, at which value the resonator was able to detect solid
10 films of the order of 0.1 μm in thickness.

The application of an on-line quartz crystal microbalance to
monitor and control the formation of organic and inorganic
precipitates from hydrocarbons and water has been described.
15 See, US Patent 5,734,098 (hereinafter "Kraus et al."). The
quartz crystal microbalance consisted of a thickness-shear mode
resonator and was described by Kraus *et al.* as being
substantially similar to those disclosed by Granstaff and
Martin. Kraus *et al.* described the use of the thickness-shear
20 mode resonator for the on-line measurement of scaling, corrosion
and biofouling in industrial processes. They also described the
use of the measurement of deposit formation to determine the
treatment required to correct the industrial process and prevent
continual deposit formation, e.g., by use of a chemical additive
25 such as an inorganic scale inhibitor. Although Kraus *et al.*
described the use of a thickness-shear mode resonator to monitor
deposit formation from hydrocarbons, industrial water and their
mixtures (including emulsions), no disclosure or suggestion was
made to the operation of these sensors in or near producing
30 hydrocarbon wells, on either a temporary or permanent basis.
Additionally, there was no disclosure or suggestion regarding
the treatment of producing hydrocarbon wells, for either organic
or inorganic deposit formation, on the basis of measurements
made by these sensors.
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A laboratory acoustic resonance technique to determine the onset
of the precipitation of wax and asphaltene from produced
hydrocarbons has been described. See, Sivaraman, A., Hu, Y.,
Thomas, F.B., Bennion, D.B. and Jamaluddin, A.K.M., "Acoustic
5   resonance: an emerging technology to identify wax and asphaltene
precipitation onset in reservoir fluids", *48th Annual Tech.
Meet. The Petroleum Society*, Calgary, Canada, June 8-11, 1997,
paper CIM 97-96; Jamaluddin, A.K.M., Sivaraman, A., Imer, D.
Thomas, F.B. and Bennion, D.B., "A proactive approach to address
10   solids (wax and asphaltene) precipitation during hydrocarbon
production", *8th Abu Dhabi Intern. Petroleum Exhibit.*, Abu
Dhabi, U.A.E., 11-14 October, 1998, SPE 49465. The spectrum of
resonant frequencies of a sample of liquid hydrocarbon in a
cylinder of fixed length and cross-sectional area was obtained
15   as a function of temperature and pressure. The resonant spectra
were collected using two ultrasonic transducers operating over
the frequency range 0-40 kHz, although significant resonances
were observed only over the frequency range 5-35 kHz. The
precipitation of wax and/or asphaltene from the liquid
20   hydrocarbon sample as the pressure and temperature of the sample
was changes resulted in changes in the frequency of the
resonances and changes in their amplitude. The changes in the
resonant spectra were attributed to changes velocity of sound in
the liquid. No reference was made to the precipitation of wax or
25   asphaltene on the transmitting or receiving transducer.

The use of a thickness-shear mode resonator to monitor the
formation of barium sulphate in samples of produced water
collected at the well head has been described. See, Emmons,
30   D.H. and Jordan, M.M., "The development of near-real time
monitoring of scale deposition", *SPE Oilfield Scale Symposium*,
Aberdeen, 27-28 Jan., 1999 (hereinafter "Emmons and Jordan").
The resonator was immersed in a fixed volume of produced water
and known amounts of soluble barium ions were added to
35   precipitate barium sulphate scale. The resonator detected the

formation of scale on its sensing surface by a decrease in
resonant frequency. The amount of barium added before scale
formation was detected by the resonator gave an indication of
the level of inhibition in the produced water. Emmons and Jordan

5   argued that the formation of scale by small additions of barium
ions indicated the produced water was close to scaling and
treatment of the well by a suitable scale inhibitor was
required. Note that this method of monitoring scale formation is
not an *in situ* method and does not measure the spontaneous

10 formation of scale under downhole conditions of temperature,
pressure, composition and flow. In addition, the resonator was
not able to clean the scale from its sensing surface. A quartz
crystal microbalance to monitor the formation of calcium
carbonate scale under laboratory conditions has been described.

15 See, Gabrielli, C., Keddam, M., Khalil, A., Maurin, G., Perrot,
H., Rosset, R. and Zidoune, M., "Quartz crystal microbalance
investigation of electrochemical calcium carbonate scaling", *J.
Electrochem. Soc.*, **145**, 2386-2395 (1998). The resonant
frequency of the microbalance was 6 MHz and calcium carbonate

20 deposition rates of 200-400 $\mu g/cm^2$ per hour were measured. The
calcium carbonate scale was observed to be the mineral calcite,
which, with an assumed density of 2.71 g/cm^3, gave deposits of
0.7-1.5 μm in thickness. The rate of scale accumulation measured
by the quartz microbalance was compared with a standard

25 electrochemical scale monitor that measured the redox current
passing through an electrode as water was reduced. The decline
in redox current gave an indirect measure of the decrease in the
surface area of the electrode as it was covered with scale and
was observed to be less sensitive to scale formation than the

30 quartz crystal microbalance. The use of a piezoelectric quartz
crystal to monitor the fouling of surfaces in a water cooling
tower by inorganic scale and bacterial growth at ambient
conditions has been described. See, Nohata, Y. and Taguchi, H.,
"An ultrasensitive fouling monitoring system for cooling

35 towers", *Materials Performance*, **34**, 43-46 (1995) (hereinafter

"Nohata and Taguchi"). Although Nohata and Taguchi did not
specifically disclose the operating frequency of the quartz
crystal, a value of about 5 MHz can be deduced from the measured
accumulation rates of 1-20 $\mu g/cm^2$ per day.

5

The use of a tuning fork for measuring the deposition of scale
in a surface process system has been disclosed. See, US Patent
5,969,235. The accumulation of scale on the tines of the tuning
fork causes a shift in the characteristic vibrating frequency of
10   the tuning fork as measured by a suitable electronic device,
such as a piezoelectric cell. The change in vibrating frequency
of the tuning fork, indicating the deposition of scale, was used
to control the addition of scale inhibitor to the process
stream.

15

Non-acoustic scale sensing techniques have also been reported. A
method of determining the accumulation of scale in petroleum
pipelines using a heat transfer sensor has been described. See,
US Patent 4,718,774. The scale formed on the external wall of
20   the sensor impeded the loss of heat from a heating element in
the sensor to the fluid flowing in the pipeline. The decrease in
heat flow was measured by means of a temperature sensor. A
wellbore scale monitor that measured the radioactivity of the
radium salts precipitated with other alkaline earth metal salts
25   has been described. See, US Patent 4,856,584 (hereinafter
"Sneider"). Sneider discloses the use of measurements of scale
radioactivity to indicate when and where the placement of scale
inhibitor is required. Another scale monitoring technique is
disclosed in US Patent 5,038,033; the radioactivity of the scale
30   was detected by a wireline gamma ray detector, correcting for
the natural gamma radiation emitted from the surrounding rock
formations.

Accurately measured pressure drops over various sections of a
35   reinjection pipeline in a geothermal power plant has been used

to monitor the growth of silica scale. See, Stock, D.D., "The
use of pressure drop measurements to monitor scale build-up in
pipelines and wells", *Geothermal Resources Council Trans.*, **14**,
1645-1651 (1990). The measured pressure drops across the
5   sections of pipe produced friction factors in the range 0.1-0.2,
compared to an expected value of 0.01. Cleaning the silica scale
from the pipeline sections using a wire brush pig resulted in
the friction factor dropping below a value of 0.06. Both
laboratory and field systems to evaluate the scaling potential
10 of oilfield brine samples by monitoring the pressure drop across
a capillary tube through which the brine flows and deposits
scale are being currently produced by the company Oilfield
Production Analysts Ltd. (see product brochures for P-MAC 2000,
3000 and 4000 series). Three optical techniques to monitor
15 fouling in industrial process systems were described in
Flemming, H-C., Tamachkiarowa, A., Klahre, J. and Schmitt, J.,
"Monitoring of fouling and biofouling in technical systems",
Water Sci. Tech., **38**, 291-298 (1998). The techniques consisted
of measurement of the intensity of light reflected from a small
20 optical fibre probe, the measurement of turbidity through
optical windows in a flow line (using periodically cleaned
windows in the flow line as a reference optical pathlength) and
an infrared spectroscopy flow cell. The accumulation of deposits
and the chemical nature of the deposits on the optical windows
25 of the infrared flow cell could be determined from the infrared
spectra.

A number of published reports have described the application of
sonic energy for cleaning producing oil wells and equipment in
30 similar industrial processes. A method of cleaning downhole
deposits, such as tar, from producing formations and production
tubing was disclosed in US Patent 3,970,146. However, no details
were given of the power or frequency of the sound used for
wellbore cleaning. A low frequency (20-100 Hz) vibrating device
35 for cleaning deposits on the walls of casing and tubing and in

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formations and gravel packs was disclosed in US Patent
4,280,557. The vibrations were generated in the device by an
orbiting mass on an unbalanced rotor, which, in turn, produced a
whirling vibratory pressure of large amplitude in the fluid in
5   the annulus. US Patent 4,320,528 disclosed a method of removing
iron oxide corrosion products and other scaling deposits from
the pipes of steam generators using a combination of high power
sound and a high-temperature solvent (e.g., sodium EDTA, citric
acid and a corrosion inhibitor). The acoustic transducers
10   operated in the frequency range 2-200 kHz and generated an
output acoustic power greater than 0.2 W/cm^2, a value which is
above the cavitation threshold of aerated water at ambient
pressure and temperature. See, Esche, R., "Untersuchung der
Schwingungkavitation in Flüssigkeiten", *Acustica*, **2**, AB208-218
15   (1952); Mason, T.J. and Lorimer, J.P., *Sonochemistry: Theory,
Applications and Uses of Ultrasound in Chemistry*, p 31, Ellis
Horwood, Chichester, UK (1988). The transducers were located
permanently on the outside of the heat exchanger tubes. US
Patent 4,444,146 disclosed an ultrasonic method to clean the
20   fouled surfaces of submerged structures, such as the hulls of
ships. The ultrasonic cleaner consisted of two ultrasonic
transducers focussed on a small area of surface to be cleaned.
The transducers operated at slightly different frequencies,
typically in the range 180-210 kHz; no details were disclosed on
25   the acoustic power required to clean the fouled surfaces. UK
Patent Application 2 165 330 A (hereinafter "D'Arcy et al.")
disclosed a method of cleaning underwater structures to depths
of up to 1000 metres using focussed ultrasound in the frequency
range 40-100 kHz. The ultrasound was generated and focussed
30   using an array of transducers located on the concave surface of
a spherical cap. The density of acoustic power at the focal
point of the array of transducers was stated to be about 500
W/cm^2, a value that is approximately 3 orders of magnitude above
the cavitation threshold of water at ambient pressure. D'Arcy *et
35   al.* suggested the high power acoustic array could be used to

clean the base of oil production platforms. US Patent 5,184,678
disclosed the design of a high power acoustic logging tool to
stimulate fluid production from oil wells. The acoustic power
was provided by pulsed magnetostrictive transducers operating in

5   the frequency range 5-30 kHz and emitting an acoustic power
density of up to 1 W/cm^2. The tool was designed to give a stand-
off from the treated formation of 0.2-0.5λ, where λ is the
wavelength of the sound in the borehole fluid. The treated
formations were exposed to the acoustic power for periods of 5-

10 60 minutes. According to US Patent 5,184,678, the applied
ultrasound reduced the viscosity of the fluid in permeable
formations and fluidised the particulate matter, thus
facilitating its removal.

15 It has been shown that ultrasound applied at a frequency of 10
kHz could remove asphaltene deposits from a sand pack saturated
with both water and kerosene at ambient pressure. See,
Gollapdi, U.K., Bang, S.S. and Islam, M.R., "Ultrasonic
treatment for removal of asphaltene deposits during petroleum

20 production", *SPE International Conf. Formation Damage Control*,
Lafayette, Louisiana, February 1994, SPE 27377. Although the
acoustic power applied to the sand packs during cleaning was not
measured, the ultrasonic transducer could generate a maximum
output acoustical power of 250 W. The authors discussed the role

25 of acoustic cavitation in the cleaning process and acoustic
cavitation was undoubtedly achieved at the power settings
reported. The asphaltene deposits were observed to be removed
significantly more efficiently by the ultrasound in kerosene
than in water. It has been demonstrated under laboratory

30 conditions that the damage caused to permeable formation by the
invasion of clay particles from drilling fluids can be partially
removed by the application of high power ultrasound. See,
Venkitaraman, A., Roberts, P.M. and Sharma. M.M., "Ultrasonic
removal of near-wellbore damage caused by fines and mud solids",

35 *SPE Drilling & Completions*, **10,** 193-197 (1995). Two ultrasonic

transducers were used; one was a high power ultrasonic horn operating at a frequency of 20 kHz with an output power of up to 250 W and the other was a low power transducer operating over frequency range 10-100 kHz. The same authors subsequently

5 evaluated the application of high power ultrasound under laboratory conditions for the removal of organic deposits and formation damage caused by the invasion of drilling fluid filtrate containing water-soluble polymers. See, Roberts, P.M., Venkitaraman, A. and Sharma, M.M., "Ultrasonic removal of

10 organic deposits and polymer induced formation damage", *SPE Formation Damage Control Symp.*, Lafayette, Louisiana, February 1996, SPE 31129. Using the same ultrasonic transducers, it was demonstrated that polymer-induced formation damage was considerably more difficult to remove than the damage caused by

15 clay fines. However, formation damage resulting from the precipitation of wax in the test core samples could be removed by sonication when the core samples were soaked in a suitable solvent.

20 US Patent 5,595,243 declosed the use of a general purpose acoustic cleaning tool for improving the near wellbore permeability of producing formations by redissolving or resuspending restricting materials. The cleaning tool was reported to generate acoustic power densities of up to 2 W/cm^2,

25 which is above the cavitation threshold for water at ambient temperature and pressure. See, US Patent 4,280,557. The tool, which consisted of an array of air-backed high power acoustic transducers of the type described by Widener, was designed to be deployed into the well on a wireline cable. See, Widener, M.W.,

30 "The development of high-efficiency narrow-band transducers and arrays", *J. Acoust. Soc. Amer.*, **67**, 1051-7 (1980); Widener, M.W., "The development of a deep submergence air-backed transducer", *J. Acoust. Soc. Amer.*, **80**, 1852-3 (1986). The transducers described by Widener would be expected to operate in

35 the frequency range 10-100 kHz. US Patent 5,676,213disclosed the

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use of high power ultrasound to remove the filter cake formed by the drilling fluid during the drilling of a well in order to measure the pressure in permeable formations. The high power ultrasound was generated by a focussing transducer operating in
5 the frequency range 100-500 kHz and capable of operating at a peak input power of up to 1 kW. US Patent 5,727,628 disclosed an ultrasonic tool for cleaning producing wells. The wireline-deployable tool consisted of an array of magnetostrictive transducers operating in the frequency range 18-25 kHz
10 (preferably at 20 kHz) and emitting an acoustic power density in the range 8-12 W/cm^2. The tool was also equipped with a pump to remove the debris of the fouling deposits disaggregated by the ultrasonic tool. US Patent 5,735,226 disclosed a method to prevent the fouling of ships and other marine structures by the
15 use of ultrasound over the frequency range 20-60 kHz. One demonstration of the technique was the location of a number of ultrasonic transducers on the hull of a ship over a period of 4 months. Over this time period the transducers, which were powered intermittently, gave effective relief from marine
20 fouling. US Patent 5,735,226 revealed no details of the power consumption of the transducers, but one embodiment of the invention consisted of the array being powered by a 9 volt battery. US Patent 5,889,209 disclosed the use of high power ultrasound to prevent biofouling of chemical sensors used in
25 aquatic environments. The ultrasound was generated by a transducer operating in the frequency range 10-100 kHz and yielding a sufficient power density (> 0.1-1 W/cm^2) to drive acoustic cavitation. US Patent 5,889,209 disclosed the use of the acoustic cleaning technique to maintain the performance of a
30 dissolved oxygen sensor located in microbiologically active water for seven days. The transducer was located over the range 4-10 mm from the active membrane of the oxygen sensor and activated for a time period of 6-90 seconds over a time interval of 5-120 minutes.
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Several papers and patents have reported on the use of high power ultrasound to accelerate the dissolution of scale by chemical scale dissolvers applied in pipelines and producing oil wells. Paul, J.M. and Morris, R.L., "Method for removing
5 alkaline scale", *International Patent Application* WO 93/24199, 9 December, 1993 describes the use of low frequency (1.5-6.5 kHz) sonic energy to accelerate the dissolution of alkaline earth metal scales using scale dissolving solutions (typically containing the chelating agents EDTA or DTPA). Gunarathne, and
10 Gunarathne and Keatch have shown that the application of low-power ultrasound can increase the rate of dissolution of barium sulphate scale using commercially available scale dissolvers; the power density was claimed to be below that required to cavitate the scale dissolving solution.
15

In conclusion, there appears to be no prior art that teaches or suggests either an acoustic scale sensor or an acoustic cleaning device located permanently or quasi-permanently in a well producing hydrocarbons. There appears to be no prior art of
20 teaches or suggests the concept of a sensor for hydrocarbon wells to monitor the formation of inorganic or organic scales, biofouling or corrosion and initiate a cleaning action. Additionally, there appears to be no prior art that teaches or suggests an on-line deposits monitoring and cleaning device
25 located on the surface facilities of a producing oil well using an ultrasonic transducer operating in its longitudinal mode and coupled to the produced fluids using a coupling material, such as an acoustic horn, to which the deposits adhere.

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SUMMARY OF THE INVENTION

5   It is an object of this invention to describe an apparatus that
can be placed at various locations to monitor the deposition of
scale and other deposits and preferably to remove such deposits.

According to the invention a deposit monitoring apparatus
10 located in a hydrocarbon wellbore is provided comprising: an
acoustic device adapted to operate in a resonance mode including
a monitoring surface directly exposed to fluids in a hydrocarbon
wellbore, wherein the deposition of material on the monitoring
surface is monitored by measuring a change in resonance
15 frequency of the acoustic device; and a power supply adapted to
supply said monitor with electrical energy.

The acoustic device is preferably mounted either permanently or
quasi-permanently in the wellbore.
20
According to another aspect of the invention, a deposit
monitoring apparatus located in a hydrocarbon wellbore is
provided, comprising: a deposit monitor adapted to measure
deposition of material on a monitoring surface that is directly
25 exposed to fluids in the hydrocarbon wellbore; a power supply
adapted to supply said monitor with electrical energy; and a
deposit removal system in communication with the deposit monitor
adapted to at least partially remove the deposition from the
monitoring surface, the deposit removal system being in a
30 control loop with said deposit monitor.

In a preferred embodiment the deposit monitor is a high power
ultrasonic transducer, operating in a longitudinal mode, coupled
to the fluids produced from the well by a solid coupling device,
35 such as an acoustic horn, for measuring the deposition of the

organic and inorganic scales that form from the fluids produced
in hydrocarbon wells. By longitudinal mode we mean that the
surface of the device exposed to the fluid is move predominantly
normal rather than parallel to the exposed surface.

5

The transducer is preferably designed to operate in the
frequency range 10-250 kHz with a maximum acoustical power
outputs of 10-500 W. The maximum power is preferably only used
during the cleaning process for less than 10 seconds or even
10 less than 1 second. More preferably the frequency range is
between 10kHz and 150kHz. The optimal frequency range is
believed to lie within the range of 50 to 100 kHz. It was found
that higher frequencies, particularly frequencies in the MHz
region, are not applicable for permanent downhole deployment.

15

The growth of wellbore deposits is monitored by the decrease in
the resonant frequency of the transducer with increasing
thickness of deposit. The resonant frequency is conveniently
determined from the real part of the admittance spectrum of the
20 transducer. The horn amplifies the effect of the scale deposit
on the measured admittance of the transducer.

The term "horn" is used as a generic expression for a solid
coupling device, sally consisting of a tapering end piece
25 mounted onto the body of the acoustic transducer. The horn can
be bolted or glued to the body of the transducer material. The
length of the horn is preferably some integer multiple of half
the wavelength of the acoustic wave generated. The tapering can
be achieved by cutting steps into the material or smoothly,
30 e.g., as exponential tapering.

The horn material can be chosen arbitrarily from a large variety
of solid materials. It is however a preferred feature of the
invention to have the horn tip made of a material that matches
35 the properties of the surrounding material, so as to ensure that

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the deposits on the surrounding material are accurately
measured.

5   At least the tip of the horn is directly exposed to the wellbore
fluid causing the deposition.

The transducer is able to detect inorganic deposits or scales,
such as barium sulphate or calcium and organic deposits, such as
waxes, at a thickness of approximately 100 µm.

10

Scales can be removed from the transducer by operation at high
power; the transducer is therefore able both to detect and clean
deposits. The ultrasonic transducer is also able to clean scale
from the surfaces of other components located at various
15   positions in producing hydrocarbon wells, such as those made of
glass, metal or plastics. The acoustic transducers can be
permanently located in producing hydrocarbon wells and indicate
the location and rate of scale deposition. The measurement of
scale deposition can be used to direct scale treatment
20   procedures, such as the placement of inhibitors or the
application of scale dissolvers, and to warn of scale
accumulation on critical downhole production equipment, such as
chokes, sliding sleeves and separators. The acoustic scale
sensor can also be used to determine the effectiveness of any
25   treatment to remove scale or other wellbore deposits.

The control loop comprises either be a suitably programmed
microprocessor or computer executing pre-programmed tasks. Or,
it could include visual display units allowing a human operator
30   to make decisions based on the measurements provided by the
deposit monitor.

Permanently or quasi-permanently installed in a wellbore or
below the surface of the Earth refers to installation that are

fixed to the wellbore and thus can be retrieved to the surface
only under great costs and even sacrifice of equipment.

These and other features of the invention, preferred embodiments
5 and variants thereof, possible applications and advantages will
become appreciated and understood by those skilled in the art
from the following detailed description and drawings.

DRAWINGS

10

FIGs. 1A-D   are schematic illustrations of examples of
                    acoustic devices, according to certain
                    embodiments of the invention;

15 FIG. 2A   shows the resonant frequencies of an acoustic
                    device shown in FIG. 1B as measured by the real
                    part of the admittance in air, water and
                    kerosene;

20 FIG. 2B   shows an enlarged part of FIG 2B;

FIG. 3   illustrates the shift of the resonant frequency
                    with increasing scale deposition at a hydrostatic
                    pressure of 272 bar (4000 psi);

25

FIG. 4   illustrates the shift of the resonant frequency
                    with increasing wax deposition at ambient
                    pressure;

30 FIG. 5   illustrates the shift of the resonant frequency
                    after cleaning the tip of a sensor;

FIG. 6   illustrates the power supply used to remove
                    deposits from a surface exposed to wellbore
35   fluids;

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FIG. 7   illustrates a downhole installation in accordance
                with the invention;

5 FIG. 8   illustrates a sensor installation with self-
                cleaning equipment in accordance with the
                invention;

   FIGs. 9A,B   illustrate further sensor installations with
10   self-cleaning equipment in accordance with the
                invention; and

   FIG. 10   shows a schematic sensor adapted to further
                analyse wellbore deposits.
15

MODE(S) FOR CARRYING OUT THE INVENTION

(I) ACOUSTIC SCALE/DEPOSITS SENSOR
20 The scale (or deposits) sensor consists of an ultrasonic
    piezoelectric transducer operating in a longitudinal mode
    coupled to a suitable metal horn. The resulting ultrasonic
    device is characterised by a sharp resonant frequency, which can
    be conveniently determined by the measurement of the admittance
25 (or impedance) spectrum of the device. The resonance frequency
    of the appropriate longitudinal mode is sensitive to any solid
    deposit that forms on the tip of the horn and the magnitude of
    the frequency shift is a measure of the mass loading. These
    ultrasonic transducers typically operate in the frequency range
30 10-100 kHz and can deliver high levels of acoustic power,
    typically in the range 1-500 W, when driven by a high input
    alternating voltage at its resonant frequency.

    FIG. 1 shows schematics of several types of acoustic horn
35 attached to an ultrasonic transducer. The basic elements of the

- 20 -

scale deposit sensor **10** are a transducer **11** made of
piezoelectric material, a power supply with electrodes **12** to
cause oscillations of the transducer, and a horn **13**. The horn is
made of aluminum. The working surface of the transducer **131**, on
5   which the deposition of the scale is sensed, is the tip of the
horn. In a downhole and surface installations, the tip **131** (or
141, 151, and 161 for the embodiments of Figures 1B, 1C, and 1D
respectively) will be exposed to wellbore/production fluids and
accumulate deposits.

10

The resonant frequency of the acoustic device operating in a
longitudinal mode is determined by the size of the piezoelectric
and the attached horn and the materials from which the
piezoelectric and metal horn are constructed. The variants
15   differ in their respective horn design. The horn **13** shown in
FIG. 1A has a stepwise tapering. In FIG. 1B, the tapering is
smooth with an exponentially reducing diameter of the horn **14**.
The horn coupled to the ultrasonic piezoelectric transducer is
made of aluminium. The resulting device has a sharp resonant
20   frequency in air of 40 kHz nominally and the area of the horn
tip was 0.2 cm^2. In FIG. 1C, the tapering is degenerated to a
single step giving the horn **15** a pin-like shape. Other horn
shapes can be envisaged, including the case where its thickness
is very much less than the wavelength of sound and the horn is a
25   thin layer of material that couples the ultrasonic transducer to
the bore hole fluids and their deposits.

Further indicated in FIG. 1 is the length of the horn as integer
multiple N of half the wavelength ($\lambda/2$) of the acoustic wave
30   generated by the transducer. FIG. 1D shows the case where the
length of the horn **16** is very much less than $\lambda/2$ and the horn
tip **161** has the same area as the ultrasonic transducer.

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Table 1 shows the resonant frequency of the ultrasonic horns and
the widths of the resonance at half peak height shown in FIG.
1A-C. The peak width of the resonance is typically 1-2% of the
resonant frequency.

5

Table 1. Resonant frequencies in air of the ultrasonic
transducers shown in FIG. 1A-C.

10

Transducer type in FIG. 1	Resonant frequency (kHz)	Width of resonance at half peak height (Hz)
A	19.86	21
B	39.04	52
C	54.63	96

FIG. 2 shows the resonant frequency of the acoustic sensor shown
in FIG. 1B as measured by the real part of the admittance in
15   Siemens (S).   The resonant frequency of the ultrasonic
transducer is modified by the nature of the fluid in which it is
immersed. FIG. 2 compares the resonant frequency of the
ultrasonic transducer immersed in air, water and kerosene. The
resonance frequency of the transducer decreases when the metal
20   horn is immersed in a denser fluid and the resonance broadens
with more viscous fluids. The fine structure (shown in FIG. 2B)
on the admittance spectra measured when the transducer is
immersed in water and kerosene at ambient pressure is caused by
the attachment of small air bubbles to the horn.

25

FIG. 3 shows the shift in the resonant frequency of a transducer
and metal horn with thickness of attached scale when the horn is
immersed in water in a pressure vessel at a hydrostatic pressure
of 4000 psi (270 bar). The resonant frequency of the 20 kHz

transducer shifts by 85 Hz per millimetre of scale of density
4.50 g/cm^3.

Further measurements show the variation of the shift in the
5 resonance frequency of a 40 kHz transducer as a function of
scale thickness in water at ambient pressure for two scale types
with densities of 2.75 and 4.50 g/cm^3. The resonant frequency of
the transducer decreases by 774 Hz per millimetre of scale of
density ρ=2.75 g/cm^3 and 966 Hz per millimetre of scale of
10 density ρ=4.50 g/cm^3.

The accumulation of inorganic scale can also be detected by a
shift in the resonant frequency of a transducer when the horn is
immersed in a liquid hydrocarbon. When comparing the admittance
15 spectra of a 40 kHz transducer and horn immersed in kerosene at
ambient pressure with and without inorganic scale attached, it
was found that the shift in the resonant frequency of the
transducer is 1317 Hz per millimetre of scale of density ρ=4.50
g/cm^3 in kerosene at ambient pressure.
20

The resonant frequency of an ultrasonic transducer and horn also
decreases when organic deposits, such as wax, form on the tip of
the horn. FIG. 4 shows the admittance spectra of a 40 kHz
ultrasonic transducer and metal horn immersed in water at
25 ambient pressure with wax of various thicknesses attached to the
tip of the horn. The resonant frequency of the transducer
decreases by 180 Hz per millimetre of wax of density 0.79 g/cm^3
when the horn is immersed in water at ambient pressure.

30 (II) ACOUSTIC SCALE/DEPOSITS CLEANING

The inorganic and organic deposits that accumulate on the tip of
the horn can be removed by applying a high alternating voltage
to the transducer. The strain produced in the transducer and the
35 attached horn breaks the bond between the horn tip and the

deposit and the tip is cleaned. The acoustic deposits sensor can
therefore be self-cleaning. The acoustic scale/deposits sensor
is also able to clean scale from the surfaces of other
components, which are either in close proximity to the tip of
5   the horn or incorporated into it.

The scale was deposited on the tip of a metal horn connected to
a 20 kHz ultrasonic transducer. The horn and transducer were
housed in the cap of a cell that can be pressurised to 340 bar
10 (5000 psi). The area of the horn tip is 2.87 cm^2, the average
scale thickness is 1.47 mm and the scale density is 4.50 g/cm^3. A
high voltage was applied to the transducer and the horn was
sonicated in a pressure cell at a hydrostatic pressure of 136
bar (2000 psi). All of the inorganic scale was removed from the
15 tip of the horn.

FIG. 5 compares the admittance spectra of the acoustic
transducer and metal horn before and after acoustic cleaning at
136 bar (2000 psi). The resonant frequency of the ultrasonic
20 transducer and metal horn changed by 210 Hz after sonication.

The electrical power that is required by the transducer to
remove the scale from the tip of the horn can be determined from
the input voltage and current. The frequency of the input
25 voltage and current is 19.84 kHz, which compares to a value of
19.81 kHz obtained from the admittance spectrum of the cleaned
horn. The scale, which consisted of a deposit with a density of
4.50 g/cm^3 and a thickness of 1.47 mm, was removed from the metal
horn at a hydrostatic pressure of 136 bar (2000 psi). FIG. 6
30 shows the input power waveform supplied to the transducer during
the cleaning of the scale. The modulus of the time-averaged
input electrical power of the waveform shown in FIG. 6 is 20.4
W.

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(III) SOME APPLICATIONS OF AN ACOUSTIC DEPOSITS SENSOR AND
CLEANER

According to the invention a permanent scale/deposits monitor is
5   provided. Ultrasonic transducers, of the type described above,
operating over a range of frequencies, typically 10-150 kHz, can
be permanently installed in a producing hydrocarbon well to
determine the rate of accumulation of scale and other deposits
(wax, asphaltene, etc.). The transducers can be deployed at
10 various locations in the well, including surface production
facilities such as subsea valves, risers, separators and any
associated pipes and conduits, in order to determine the
location of scale formation. The transducers can be used to
determine the rate of accumulation of scale and other deposits
15 and these measurements can be used to select the appropriate
treatment to maintain the productivity of the well, such as the
deployment of scale inhibitors or scale dissolvers. The deposits
accumulated on the horn attached to the transducer can be
cleaned periodically to maintain its sensitivity.
20

According to the invention the apparatus can be used in the
maintenance of intelligent completions. More specifically, the
ultrasonic sensor can be used to determine the accumulation of
scale, wax or asphaltene on critical downhole equipment, such as
25 chokes, valves and the sliding sleeves on intelligent completion
systems. The measurements can be used to select an appropriate
treatment to maintain the integrity and operation of the
equipment, e.g., deployment of a scale dissolver to remove scale
from critical components.
30

In FIG. 7 reference is made to an "intelligent" completion
system deployed to control the flow of wellbore fluid into a
production pipe.

- 25 -

FIG. 7 shows a schematic of part of an intelligent completion
system. An intelligent completion allows active control of
downhole processes such as flow rate measurements and control. A
wellbore **70** is shown with a casing **701** installed. At certain
5 locations the casing **701** is perforated by holes 702 to allow
wellbore fluid to enter the wellbore. Installed within the
wellbore is a production pipe **71** with a slotted section **711**.
Wellbore fluid enters the production pipe via the slotted
section **711**. Mounted within the production pipe is a sliding
10 sleeve **712**. The sliding sleeve **712** controls the flow of
reservoir fluids into the production tubing from a particular
section of the well. The flow rate, pressure and temperature of
the production fluids are measured by a sensor sub **713** near the
slotted section **711** into the tubing. The sliding sleeve **712** is
15 operated by a downhole electrical motor **714** that is powered by
means of an electrical cable **721** from the surface **72**.

One problem associated with the use of a sliding sleeve is the
formation of wellbore deposits, such as inorganic scale or wax,
20 on the sleeve or its track. It is common practice to design the
completion hardware such that the electric motor **714** is
sufficiently powerful to remove small amounts of scale when the
sleeve is moved. However, attempting to remove scale or other
deposits by scraping with the sleeve **712** may result in damage to
25 the track and possible jamming. The location of an acoustic
scale sensor **715** close to the sliding sleeve **712** will enable the
accumulation of deposits on completion hardware to be assessed
quantitatively through control equipment **722** located at the
surface. Transfer of energy and data signal between control
30 equipment **722** and the sensor **715** is done via wiring **716** run with
the production tubing. If scale accumulation on the sleeve is
considered to be above a level at which it can be safely
operated, then an external scale removal process may be required
(e.g., application of a scale dissolver solution).

Alternatively, the control equipment **722** could be used to
activate the sleeve periodically or responsive to a threshold
amount of deposit as measured by the scale sensor **715**. In yet
another alternative the control equipment **722** could at least
5 partly be incorporated into the downhole installation. By thus
providing a direct feedback control between sleeve and deposit
monitor **715**, the amount of intervention from the surface can be
reduced.

10 According to the invention, acoustic cleaning of scale and other
deposits is provided. The ultrasonic transducer and associated
horn can be used to remove scale and other deposits (wax,
asphaltene, etc.) from critical components that are used in
measurement devices exposed to wellbore/production fluids in the
15 wellbore or on the surface. The components can be part of
measurement systems that are either permanently installed in
producing hydrocarbon wells or surface facilities or temporarily
exposed to the fluids produced by the hydrocarbon well, e.g., on
a wireline-deployable tool. Critical components exposed to
20 wellbore fluids that may require cleaning include separation
membranes, optical windows and electrical contacts such as
electrodes.

FIG. 8 refers to a venturi-type flowmeter having a gamma-ray
25 sensor in its constriction section.

It shows a schematic of a gradio-venturi tube **81** located in the
tubing **80** of a producing hydrocarbon well. The section of
tubing 80 can be located either in a well or on surface
30 facilities. Located within the constriction formed by the
venturi **81** is a gamma ray sensor **82**. Details of those known
components of a gradio-venturi can be found for example in US
Patent No. 5,591,922. The gamma ray sensor, which consists of a
gamma ray source **821** (frequently a dual energy source) and a
35 gamma ray detector **822**, such as a photomultiplier tube. The

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gamma rays enter and leave the tube by means of nuclear windows
823 made of a material such as boron carbide. Gamma-ray devices
as described above are known as such and described for example
in the U.K. Patent Application No. 9919271.8.

5

A significant problem faced by the gamma ray density measurement
is the accumulation of inorganic or organic scales on the
nuclear windows **823**. For example, the accumulation of small
amounts of barium sulphate (barite) scale may result in a

10 serious overestimate of the density of the production fluids.
Similarly, the accumulation of radioactive scales on the nuclear
windows may give rise to erroneous measurements. The
accumulation of organic scales, such as asphaltenes that may
contain elements with of high atomic number, can also corrupt

15 the density measurement.

One solution to the problem of deposits accumulation on the
nuclear windows **823** is to incorporate them into a high power
ultrasonic transducer and horn as is the subject of the present

20 invention (see FIG. 1 above). FIG. 8 shows the two windows
located in a hollow horn **824** and transducer **825**; the windows **823**
are cleaned by operating the transducer in its high power mode.
The accumulation of deposits on the windows can be measured by a
shift in the resonance frequency of the transducer and horn, as

25 described above.

The gradio-venturi tube of the type above can be located either
on the surface or downhole, e.g., as part of an intelligent
completion system.

30

FIG. 9 shows further examples of the use of an ultrasonic
transducer and horn to clean measurement devices that may be
deployed in a producing hydrocarbon well or at surface
installation monitoring the flow of hydrocarbon from the well.

35

FIG. 9A shows a schematic of an optical window **931** located at the tip of a horn **93** attached to an ultrasonic transducer **91**. The optical window **931**, which can be made of a suitably resistant material such as diamond or sapphire, can be connected

5   to a source and detector using an optical fibre **95** or other optical conduit such as a light pipe. The optical transmission of the window can be maintained by removing deposits of organic and inorganic scales with ultrasonic cleaning. The accumulation of deposits on the optical window can be determined by either

10 the decreased transmissivity of the window or the change in the admittance spectrum of the transducer **91** and horn **93** assembly. The optical windows can be located either in a producing oil well, on a permanent of quasi-permanent basis, or on the surface facilities. The acoustic cleaning of optical windows can also be

15 applied to wireline logging tools, such as the optical windows used in the Optical Fluid Analyser in Schlumberger's Modular Dynamics Formation Tester tool (described in U.S. Patent No. 4,994,671) or the windows used in the optical probes to monitor multiphase production from hydrocarbon wells, as described in

20 U.S. Patent No. 5,831,743.

FIG. 9B shows a schematic of an ultrasonic transducer **91** and horn **94** used to clean the membrane **961** of an ion selective electrode **96** that could be used to measure the activity of an

25 ionic species in the water produced from a hydrocarbon well. The performance of the membrane **961** is maintained by the cleaning action of the ultrasonic transducer **91** and horn **94**, which are in close proximity to the membrane. The ultrasonic cleaning technique can be used to maintain the permeability of membranes

30 used to separate various components from the fluids produced from hydrocarbon wells, e.g., gas extraction membranes, oil-water separation membranes. Note that a separation membrane and electrode can also be incorporated into the horn coupled to a transducer. The separation membranes can be similarly located in

a producing wellbore or in the surface facilities of a producing well.

According to the invention, a method for the identification of
5   scale type is provided. The resonant frequency of the transducer
and horn responds to the mass of the attached deposits and it
may not be possible to identify the type of scale deposit in the
absence of other measurements. One of a variety of measurements
could be used to identify the type of scale deposit accumulated
10 on the acoustic horn and thus enable acoustic scale sensor to
measure the thickness of the deposit. Two examples are give.
Firstly, a spectroscopic measurement could be employed, using an
optical widow of the design shown in FIG. 9A. The scale type can
identified by a total internal reflection spectroscopic
15 technique, such as infrared spectroscopy, or Raman spectroscopy,
which, as reflection and scattering techniques, are insensitive
to the thickness of the scale layer. A second possible technique
is to use a second acoustic sensor, embedded in the acoustic
horn, to measure the acoustic transit time through the scale
20 deposit.

FIG. 10 shows a schematic of the acoustic sensor used to measure
the acoustic transit time ΔT_t through the scale film. This
acoustic sensor could be used either downhole or above ground on
25 the surface facilities. Pulsed ultrasound is emitted from an
emitting transducer **981** and the reflections are collected by a
second receiving transducer **982**. The acoustic impedance Z of the
scale layer **99** can be estimated by the measured values of the
mass W of scale attached to the acoustic horn **97** and ΔT_t. The
30 thickness of scale h attached to the horn is related to W by

[1] $$h = \frac{W}{\rho_s A}$$

- 30 -

where ρ_s is the density of the scale and A is the area of the tip of the horn. The thickness h is related to ΔT_t by

$$[2] \qquad h = \frac{\Delta T_t V}{2} \, ,$$

5

where V is the velocity of sound in the scale layer. The combination of eqn.[1] and [2] gives

$$[3] \qquad Z = \rho_s V = \frac{2W}{\Delta T_t A} \, .$$

10

The scale type can be discriminated by the measured value of Z. Table 4 shows the values of the acoustic impedance Z as a function of scale type. When Z is identified the thickness h of the scale deposit can be calculated using eqns.[1] or [2] using

15   the known values of V and ρ_s.

Table 4. Values of the acoustic impedance Z for various inorganic scales.

20

Scale type	Acoustic impedance Z $(kg/m^2s \times 10^{-6})$
calcite	17.6
anhydrite	18.0
celestite	19.1
barite	19.9

According to the invention monitoring scale/deposits removal techniques are provided. The acoustic scale sensor can be used to evaluate the efficiency of an external scale removal

25   treatment process, such as a scale dissolver solution or a physical scale removal technique. The scale removal treatment can be monitored in real time using the change in the resonant frequency of the transducer and horn. The acoustic scale monitor

can therefore be used as part of a scale maintenance service
that monitors scale accumulation and evaluates the
cleaning/removal process. The maintenance service can be applied
to the accumulation of scale both in a producing wellbore or in
5   the surface equipment.

According to the invention, fluid composition and pressure
effects can be determined. The resonant frequency of the
ultrasonic transducer and horn with no deposits attached depends
10   on the composition of the fluid with which it is in contact and
its hydrostatic pressure. A change in the composition of the
produced fluid or its hydrostatic pressure may therefore obscure
the change in resonant frequency due to the accumulation of
inorganic or organic deposits. A change in resonant frequency
15   due to a change in fluid properties can be measured using a
second matched transducer and horn, which is in close proximity
to the scale detector. The second transducer is cleaned
frequently to ensure that the horn is always free from inorganic
and organic scales and that the changes in its resonant
20   frequency are solely caused by changes in fluid composition and
pressure.

Surface Modification of Acoustic Horn. An important aspect of a
scale/deposits sensor permanently installed in a producing
25   hydrocarbon well or in the surface facilities is that the rate
of accumulation of deposits must be the same as that of the
region of the wellbore it is monitoring. The composition and
morphology of the surface of the tip of the horn should be such
as to give the same rate of scale accumulation as the solid
30   surfaces in the close environs of the sensor. The surface of the
horn tip should be suitably controlled by the choice of material
and/or coating. The material and coating used to fabricate the
horn should be able to withstand repeated sonication.

Size of Transducer and Horn. The size of an ultrasonic transducer and horn may be a critical issue for the permanent placement of such a device for scale/deposits monitoring. The size of the transducer and horn are largely determined by the

5   desired frequency of operation and the materials use to them. High power ultrasonic transducers and horns in the size range 5-6 cm, which operate in the frequency range 89-113 kHz, have been reported by Lal and White. See, Lal, A. and White, R.M., "Silicon microfabricated horns for power ultrasonics", *Sensors*

10 *and Actuators*, **A54**, 542-546 (1996). The acoustic horns were microfabricated from silicon wafers.

While preferred embodiments of the invention have been described, the descriptions and examples are merely illustrative

15 and are not intended to limit the present invention.

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CLAIMS

What is claimed is:

5   1.   A deposit monitoring apparatus located in a
hydrocarbon wellbore comprising:
            an acoustic device adapted to operate in a resonance
       mode including a monitoring surface directly exposed to
       fluids in a hydrocarbon wellbore, wherein the deposition of
10   material on the monitoring surface is monitored by
       measuring a change in resonance frequency of the acoustic
       device; and
            a power supply adapted to supply said monitor with
       electrical energy.

15

       2.   The apparatus of claim 1, wherein the acoustic device
is mounted either permanently or quasi-permanently in the
wellbore.

20   3.   The apparatus of claim 1, wherein the acoustic device
operates in a longitudinal mode.

       4.   The apparatus of claim 3, wherein the acoustic device
further comprises a transducer, and a focussing element coupled
25 to the transducer.

       5.   The apparatus of claim 4, wherein the focussing
element is an acoustic horn.

30   6.   The apparatus of claim 1, wherein the resonance
frequency of the acoustic device is in the range of 10 kHz to
150 kHz.

7. The apparatus of claim 6 wherein the resonance frequency of the acoustic device is in the range of 50 kHz to 100 kHz.

5   8. The apparatus of claim 1, wherein the monitoring surface is located on or near one of the following devices switches, valves, sleeves, mandrels, downhole separators and sensors located in the wellbore.

10   9. The apparatus of claim 1 further comprising a deposit removal system adapted to at least partially remove the deposition from the monitoring surface, the deposit removal system being in a control loop with said deposit monitor.

15   10. The apparatus of claim 9, wherein the deposit removal system includes a deposition inhibiting or removing chemical agent.

11. The apparatus of claim 9, wherein the deposit removal
20   system uses the acoustic device to exert a physical force onto the deposited material.

12. The apparatus of claim 9, wherein the deposition removal system is near a sensor having a surface exposed to the
25   fluids and the deposition removal system is adapted to remove deposits from said exposed surface.

13. The apparatus of claim 12, wherein the sensor is selected from a group comprising optical sensors, electro-
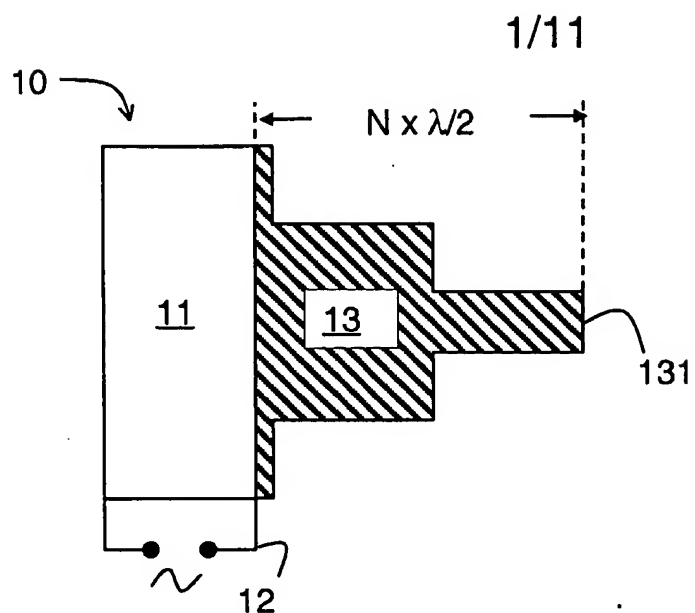30   chemical sensors, or acoustic sensors.

14. The apparatus of claim 11, wherein the exposed sensor surface is selected from a group comprising optical windows, membranes, or sensitive areas of acoustic sensors.

35

15.   The sensor of claim 1, wherein the sensor includes an additional sensing system to analyze material deposited on the monitoring surface.

16.   A deposit monitoring apparatus located in a hydrocarbon wellbore, comprising:

        a deposit monitor adapted to measure deposition of material on a monitoring surface that is directly exposed to fluids in the hydrocarbon wellbore;

        a power supply adapted to supply said monitor with electrical energy; and

        a deposit removal system in communication with the deposit monitor adapted to at least partially remove the deposition from the monitoring surface, the deposit removal system being in a control loop with said deposit monitor.

17.   The apparatus of claim 16, wherein the monitoring surface is located on or near one of the following devices: switches, valves, sleeves, mandrels, downhole separators and sensors located in the wellbore.

18.   The apparatus of claim 16 wherein the deposit monitor further comprises an acoustic device adapted to operate in a resonance mode, wherein the deposit monitor measures deposition of the material on the monitoring surface by measuring a change in resonance frequency of the acoustic device.

19.   The apparatus of claim 18, wherein the acoustic device operates in a longitudinal mode.

20.   The apparatus of claim 18, wherein the acoustic device further comprises a transducer, and a focussing element coupled to the transducer.

21.   The apparatus of claim 18, wherein the resonance frequency of the acoustic device is in the range of 10 kHz to 150 kHz.

5   22.   The apparatus of claim 18, wherein the deposit removal system includes a deposition inhibiting or removing chemical agent.

23.   The apparatus of claim 18, wherein the deposit removal
10   system includes elements adapted to exert a physical force onto the deposited material.

24.   The apparatus of claim 18, wherein the deposition removal system is near a sensor having a surface exposed to the
15   fluids and the deposition removal system is adapted to remove deposits from said exposed surface.

25.   The apparatus of claim 18, wherein the sensor is selected from a group comprising optical sensors, electro-
20   chemical sensors, or acoustic sensors.

FIG. 1A

FIG. 1B
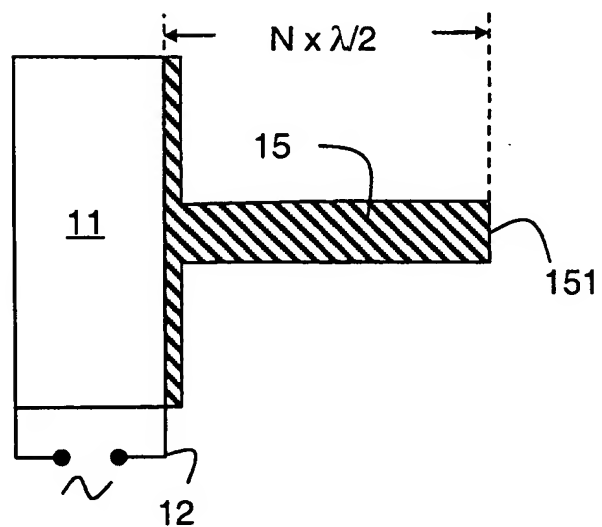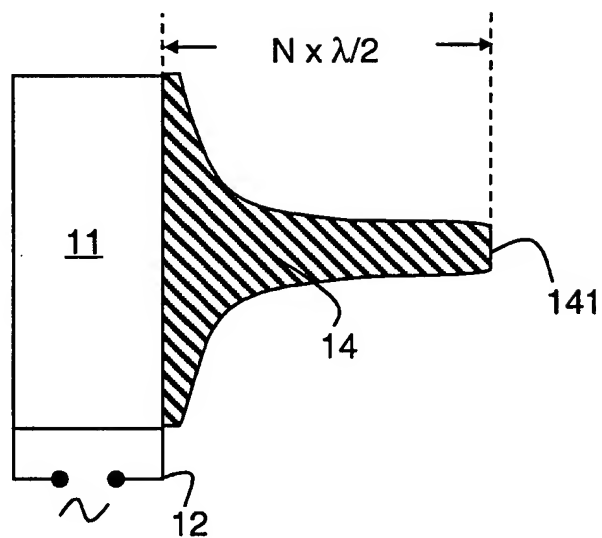
FIG. 1C
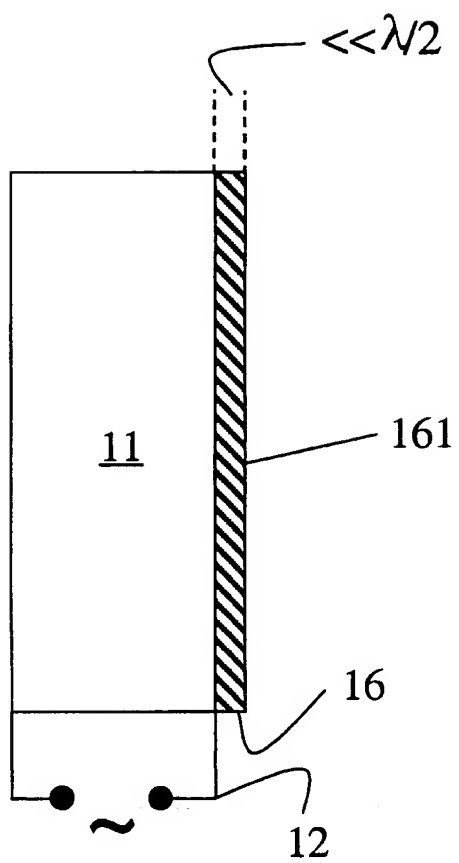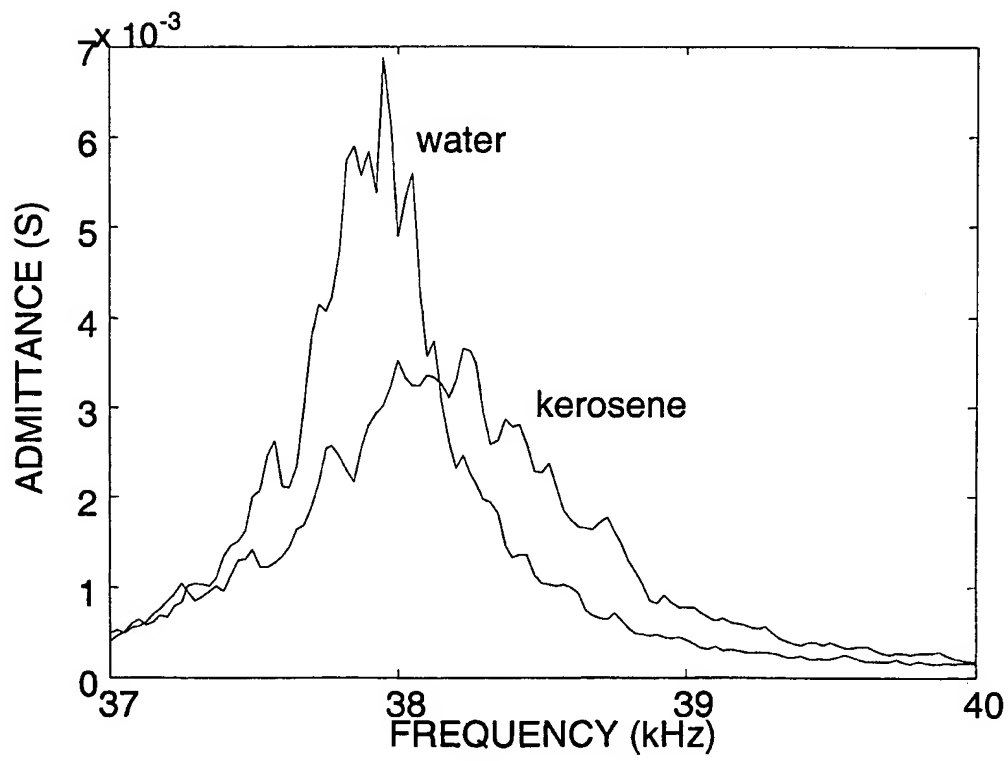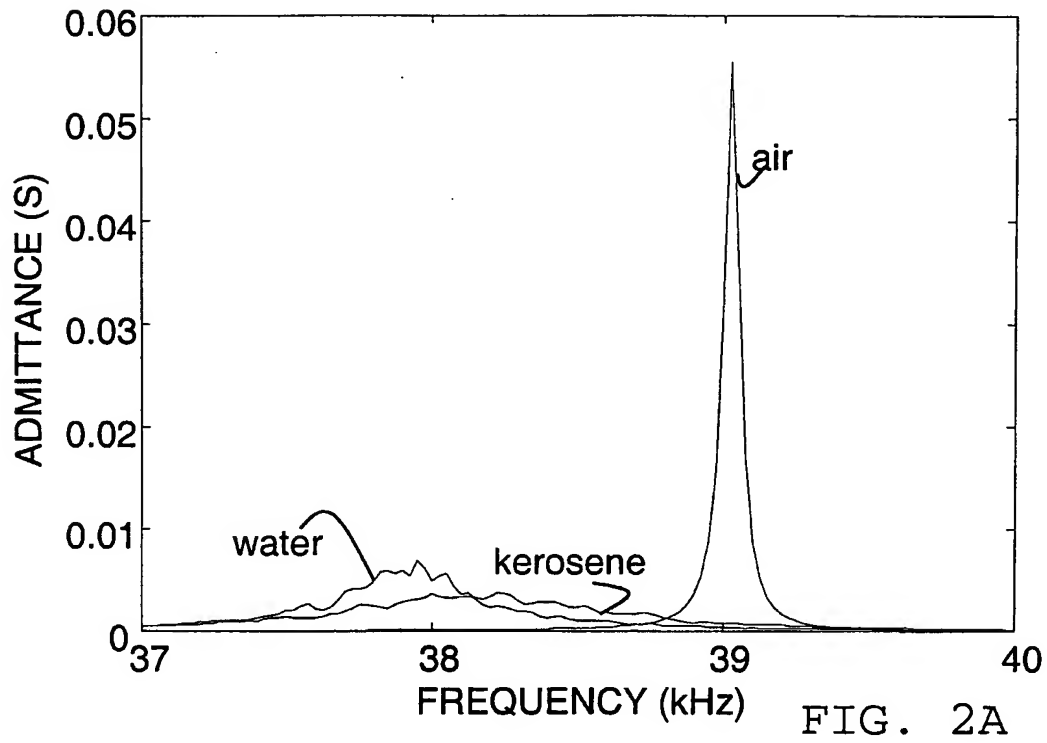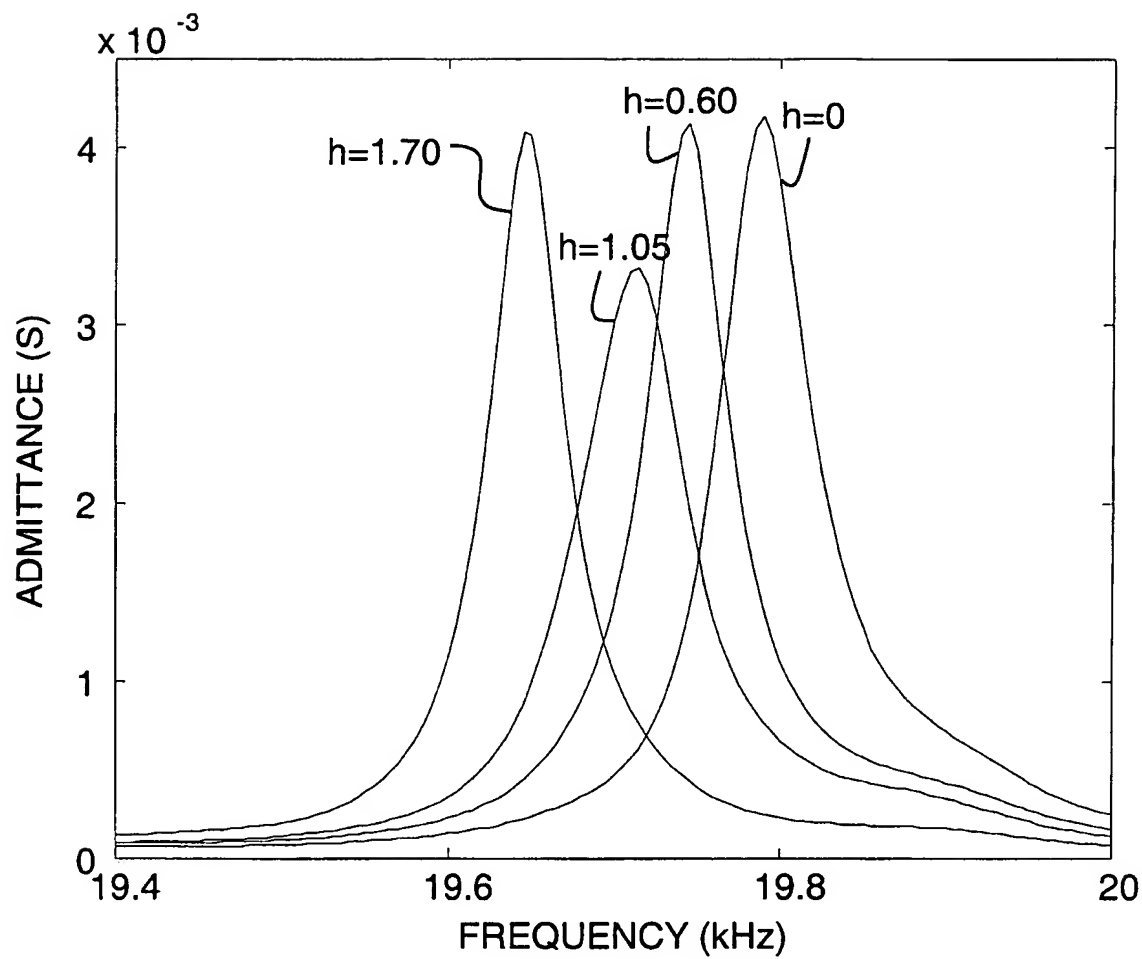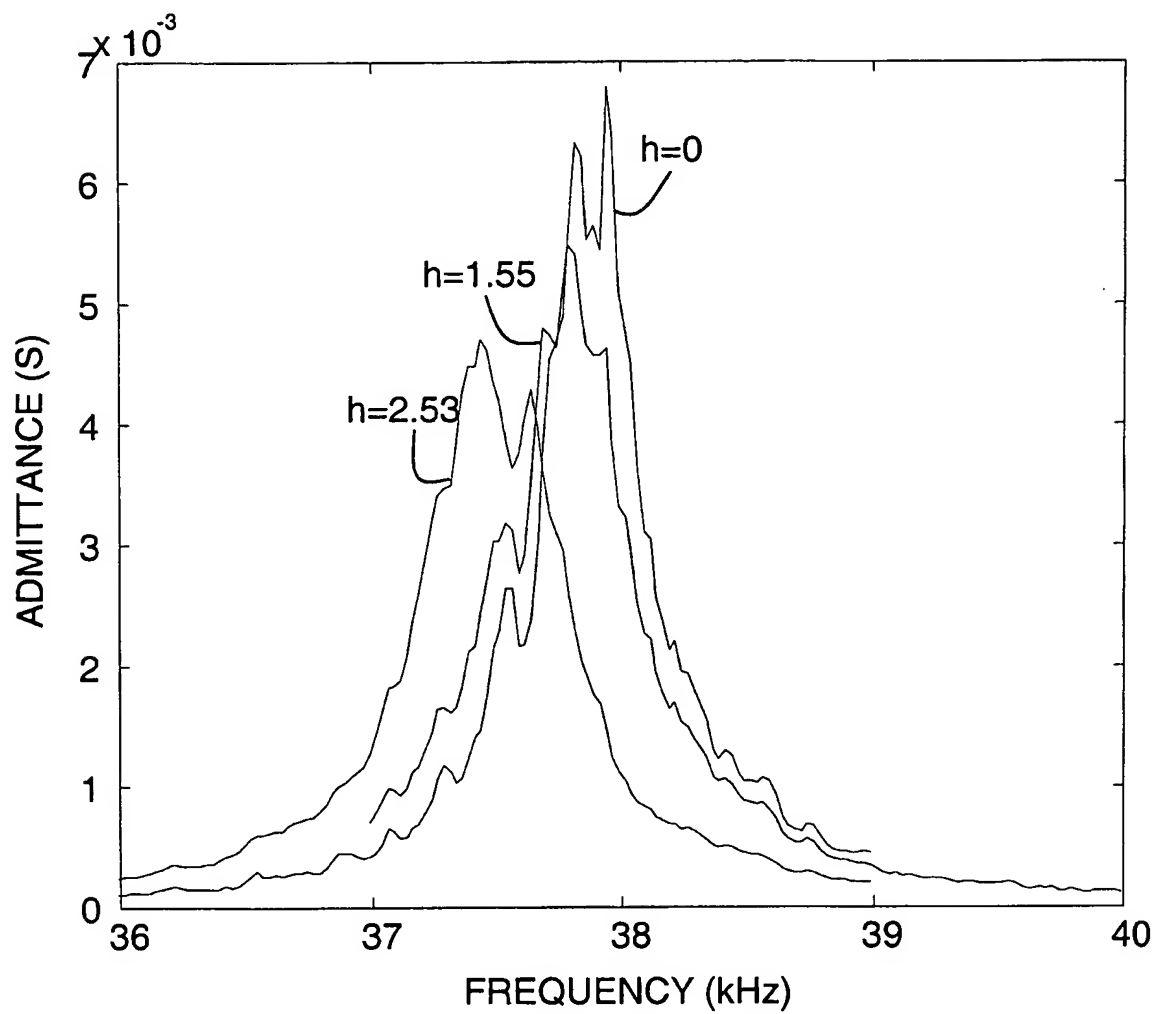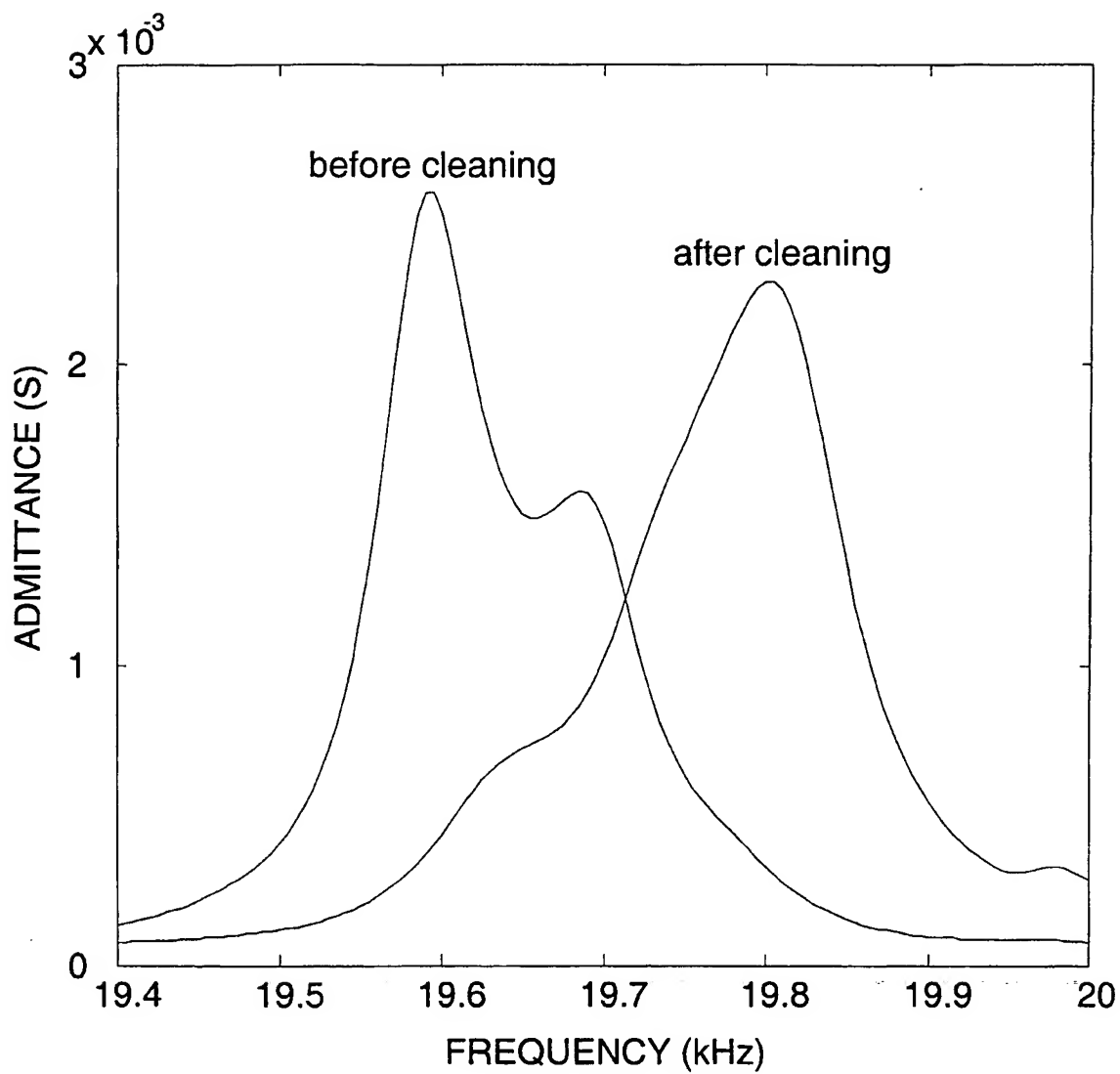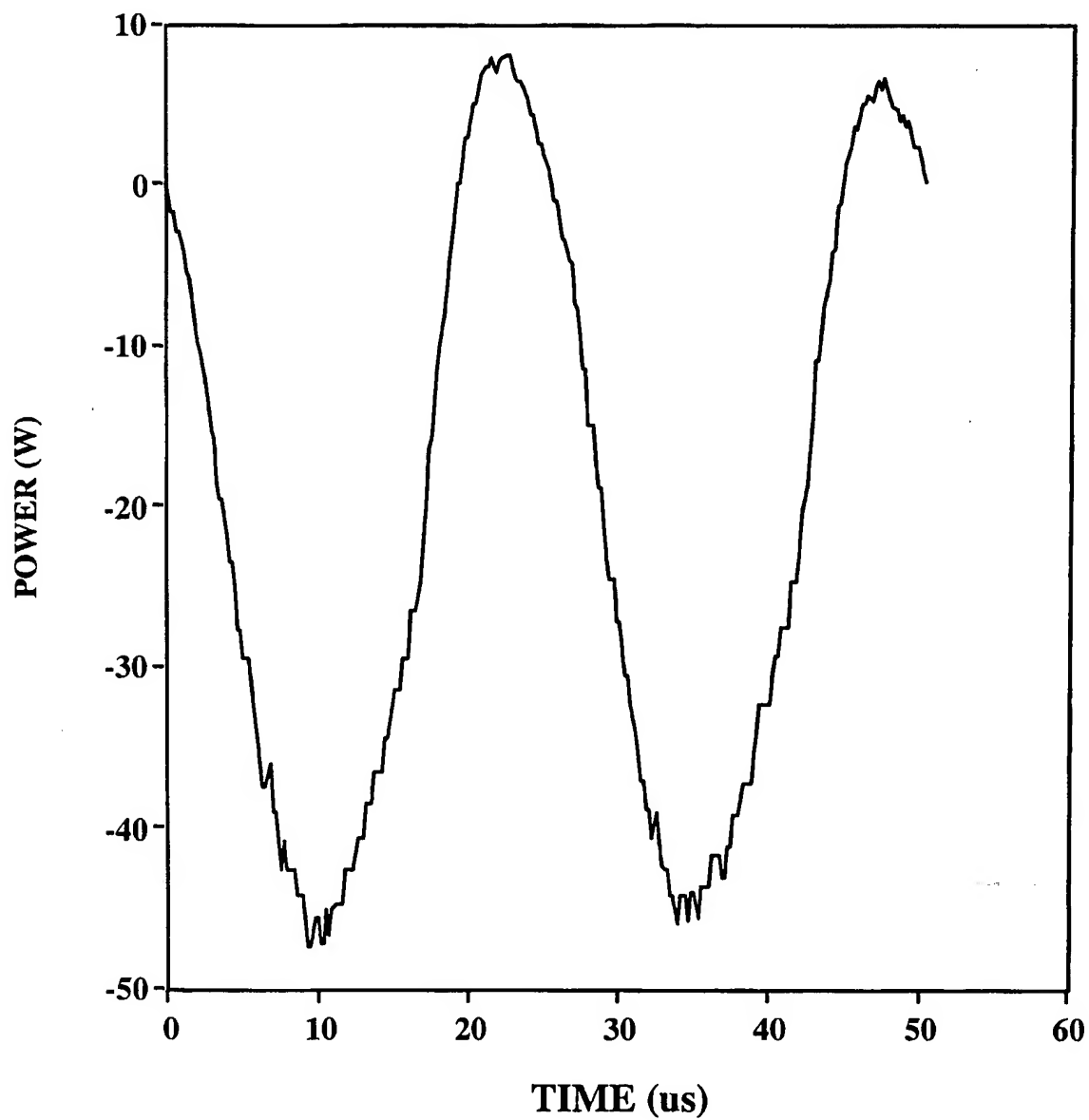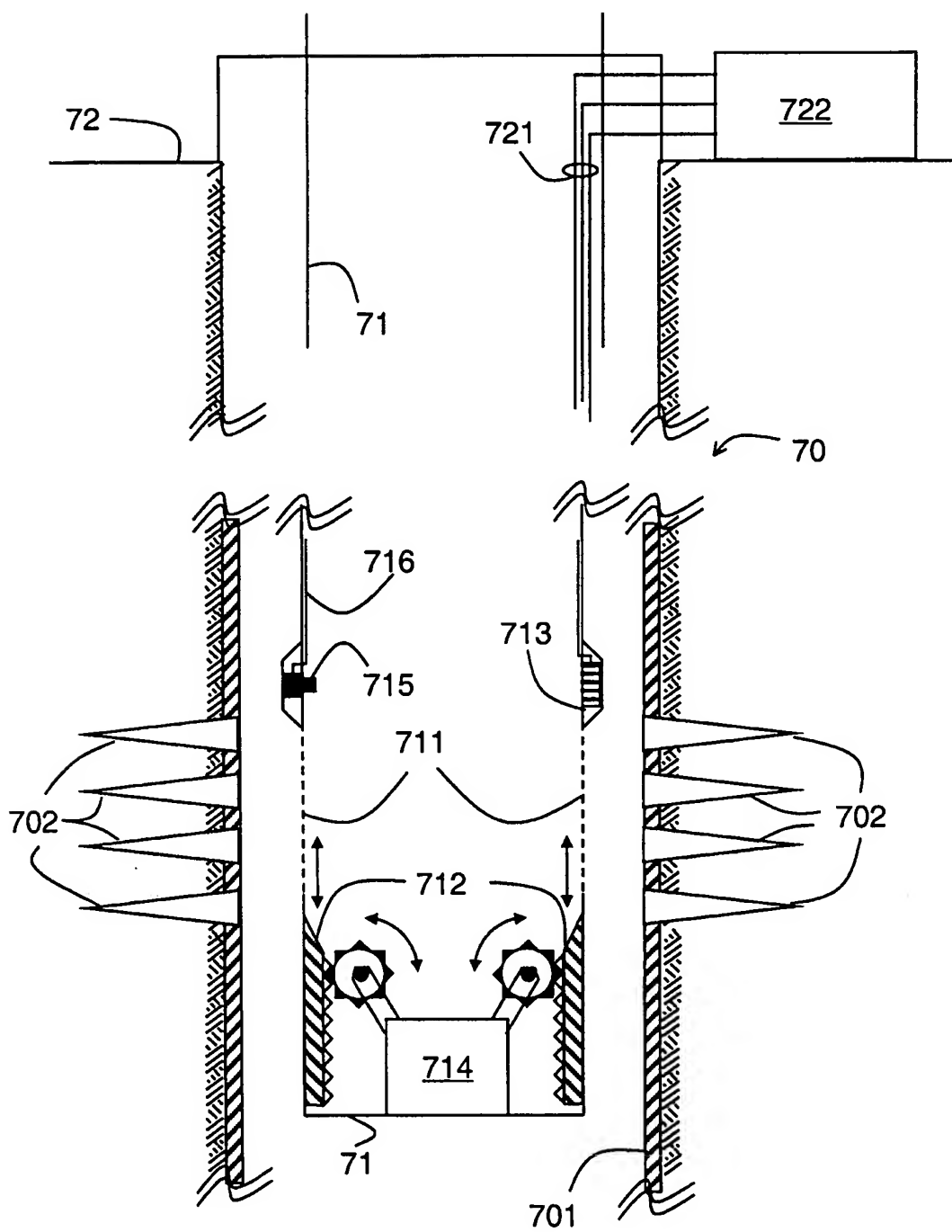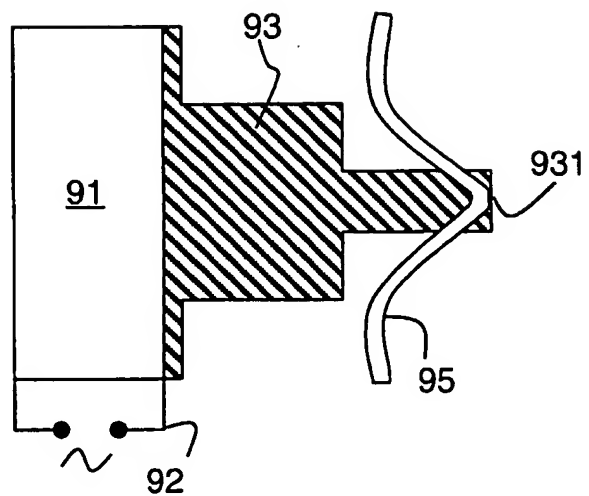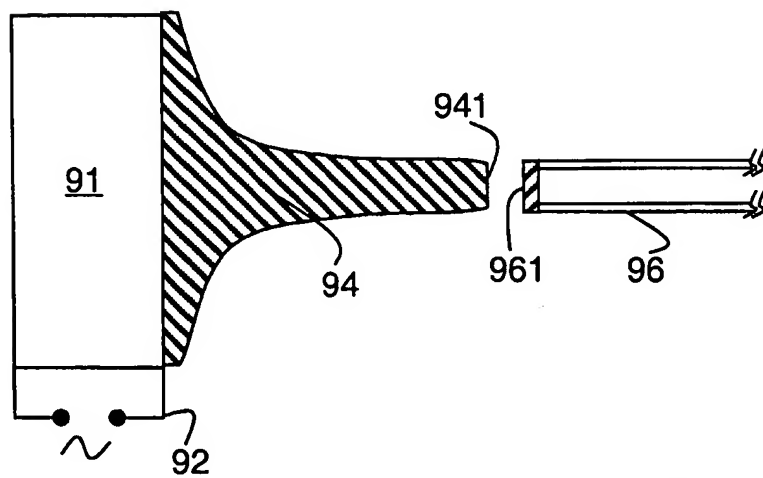
FIG. 1D

FIG. 2A

FIG. 2B

FIG. 3

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FIG. 4

FIG. 5

FIG. 6

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FIG. 7

FIG. 8

FIG. 9A

FIG. 9B
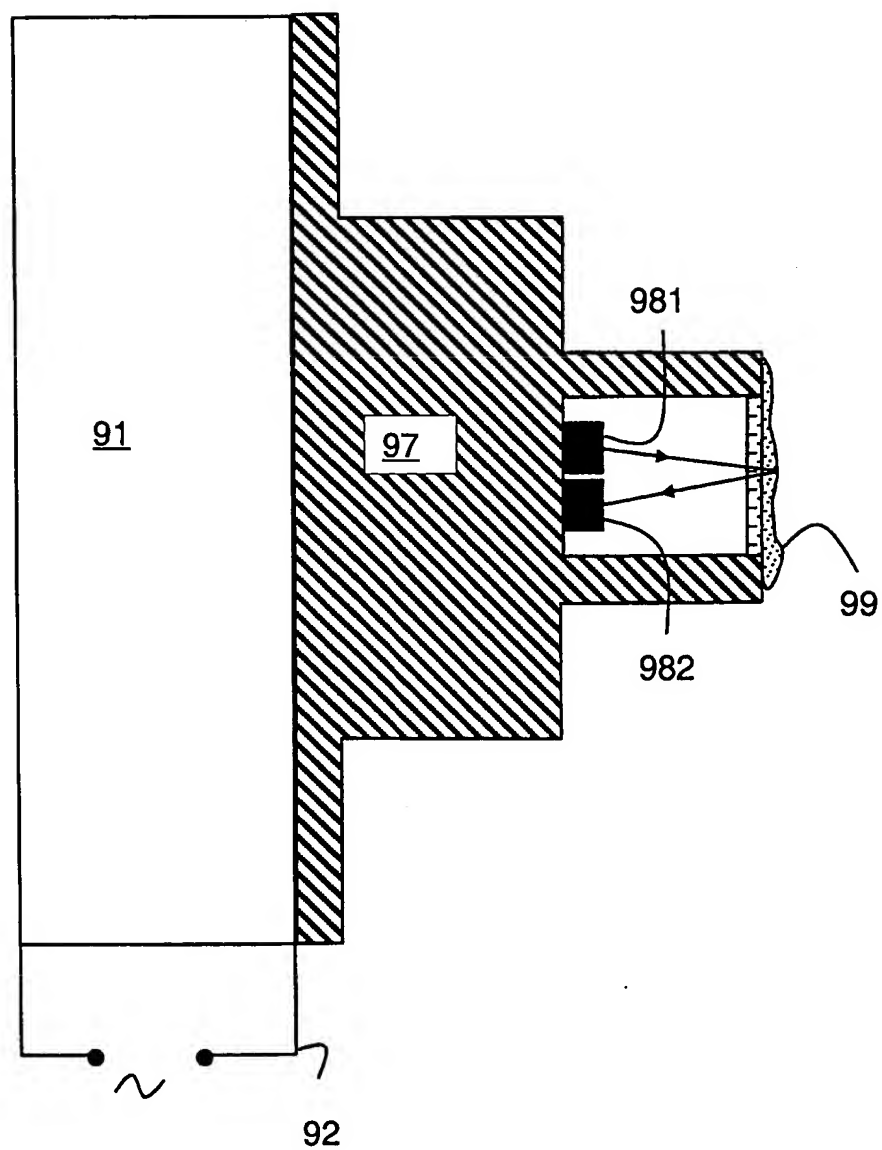
FIG. 10

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7   G01N29/02   G01G3/16   B08B7/02   E21B37/00   G01N5/00
        G01N33/28

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7   G01N   G01G   B08B   E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 661 233 A (SPATES JAMES J ET AL) 26 August 1997 (1997-08-26) cited in the application column 2, line 30 - line 38 column 4, line 10 - line 25 column 8, line 20 - line 62 column 13, line 20 - line 28 column 13, line 55 - line 65 column 14, line 4 - line 38 ___ -/--	1,16

[X] Further documents are listed in the continuation of box C.   [X] Patent family members are listed in annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 February 2001	21/02/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Hocquet, A

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INTERNATIONAL SEARCH REPORT

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X	EMMONS ET AL.: "on-site, near real time monitoring of scale deposition" PROCEEDINGS OF SPE 1999 CONFERENCE ' PRODUCTION OPERATIONS AND ENGINEERING', vol. 2, 3 - 6 October 1999, pages 389-394, XP000979810 Houston (USA) cited in the application page 392, column 1, paragraph 4 -column 2, paragraph 3 page 390, column 2, paragraph 1 - paragraph 2 ----	1,16
X	US 5 969 235 A (ALLAN GRAEME) 19 October 1999 (1999-10-19) cited in the application column 3, line 42 -column 4, line 19; figures	1
X	column 1, line 9 - line 14 ---	16
X	US 5 646 338 A (DECLERCQ GHISLAIN ET AL) 8 July 1997 (1997-07-08) column 1, line 19 - line 54 column 5, line 50 - line 60 column 6, line 17 - line 39 column 8, line 30 - line 51	1,16
A	column 9, line 12 - line 43 ---	10
A	US 5 595 243 A (MAKI JR VOLDI E ET AL) 21 January 1997 (1997-01-21) column 4, line 38 - line 41 column 5, line 5 - line 16; figures 3-5 ---	1,16
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A	column 8, line 6 - line 19 ---	11,24
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 112 642 A (WAJID ABDUL) 12 May 1992 (1992-05-12) column 1, line 5 - line 14 column 1, line 40 - line 49 column 9, line 39 - line 54 -----	1

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